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**Congestion pricing and inter-temporal preferences rate integration in social welfare function**

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## **Abstract**

Assessing social benefits in transport policy implementation has been studied by many researchers using theoretical or empirical measures. However, few of them measure social benefit using different discount rates including the inter-temporal preferences rate of users, the private investment discount rate and the inter-temporal preferences rate of the government. In general, the social discount rate used is the same for all social actors. Therefore, this paper aims to assess a new method by integrating different types of discount rate belonging to different social actors in order to measure the real benefits of each actor in the short, medium and long term. A dynamic simulation is provided by a strategic Land-Use and Transport Interaction (LUTI) model. The method is tested by optimizing a cordon toll scheme in Madrid considering socio- economic efficiency and environmental criteria. Based on the modified social welfare function (WF), the effects on the measure of social benefits are estimated and compared with the classical WF results as well. The results of this research could be a key issue to understanding the relationship between transport system policies and social actors' benefits distribution in a metropolitan context. The results show that the use of more suitable discount rates for each social actor had an effect on the selection and definition of optimal strategy of congestion pricing. The usefulness of the measure of congestion toll declines more quickly over time.

## INTRODUCTION AND RELATED WORK

Research on “welfare economics” focuses on the pursuit of the statement “X has higher welfare in scenario A rather than B” which implies that “X prefers scenario A to B”. This value judgment, innocent and independent at first, involves many questions: whose preferences should count? Over what period of time? How should these preferences be counted? All these concerns must somehow be integrated into a social policy formulation.

There exists different manner for defining a welfare function. Traditionally, welfare economic theory foundation is based on a Net Present Value (NPV) calculation where the time dependent preferences of considered agents need to be taken in account. However, the time preferences, remains a controversial subject. Currently, the traditional approach employs a unique discount rate for various agents. However, this way of discounting appears to be inconsistent with the rhetoric and spirit of ‘sustainable development’ (1). New research work suggests that the discount rate may not be a homogeneous value. The discount rates may change during time following the individual’s preferences. A significant body of evidence suggests that people do not behave following a constant discount rate (2), (3). In fact, UK Government has quickly recognized the power of the arguments for time-varying rates, as it has done in its official guidance to Ministries on the appraisal of investments and policies (4). Other authors deal with not just time preference but with uncertainty about future income (precautionary saving). In a situation in which economic growth rates are similar across time periods, the rationale for declining social optimal discount rates is driven by the preferences of the individuals in the economy, rather than expectations of growth (5). However, these approaches have been mainly focused on long-term policies where intergenerational risks may appear (6), (7).

The traditional cost-benefit analysis (CBA) uses a unique discount rate derived from market interest rates or investment rates of return for discounting the costs and benefits of all social agents included in the CBA (8). However, the costs of opportunity may differ amongst individuals, firms, governments, or society in general, as do the returns on savings. In general, the firms or operators require an investment rate linked to the current return on savings, while the discount rate of consumers-users depends on their time preferences with respect of the current and the future consumption, as well as society can take in account the intergenerational well-being, adopting a lower discount rate for today’s generation. Time discount rate of social actor (users, operators, government and society) places a lower value in a future gain and the uncertainty about future income strongly determine the individual preferences. These time and uncertainty dependent preferences must be integrated into a transport policy formulation that has significant social impacts. The use of individual social agent discount rate drives the optimization process by a LUTI model more credible. The discount rate of a user cannot be the same than the operator’s discount rate. The preferences of both are different.

In addition, another school of thought suggests that people, such as a social group, may have different attitudes towards future costs and benefits (9). Particularly, the users have different discount rates related to their income. Some research work tried to modify user discount rates using a compensating weight which represents the inverse of household income level. The discount rate is important in order to make acceptable or not a policy or investment by considering if the discounted value of benefits exceeds the discounted value of the costs. Therefore, the economic theory on which welfare assessment is based has various implications for investment policies including transport policies (10).

Congestion, pollution, resource consumption, social exclusion, and deterioration of quality of life are some of the problems that authorities must deal with in the coming years due to the intensive and continuous growth of car usage. Society finds congestion inefficient and wasteful. Hence, it has been the transportation external cost attracting the attention of many economists, engineers and urban planners.

Extra travel time has been one of the main motivations for investment in transport infrastructure and services.

One of the measures proposed for road congestion is congestion pricing following the *Pigouvian* thinking of charging for the external costs (11). Congestion pricing has been studied in a very large amount of settings: with steady-state congestion models, using queuing models, taking into account network equilibrium and considering all sorts of secondary issues such as time-dependent charges (12), (13). But from the earliest Walters (14), Vickery (15), UK Ministry of Transport (16), to the most recent works (17), (18), (19) one of the main interests has been to define the optimal price in order to maximize the social welfare.

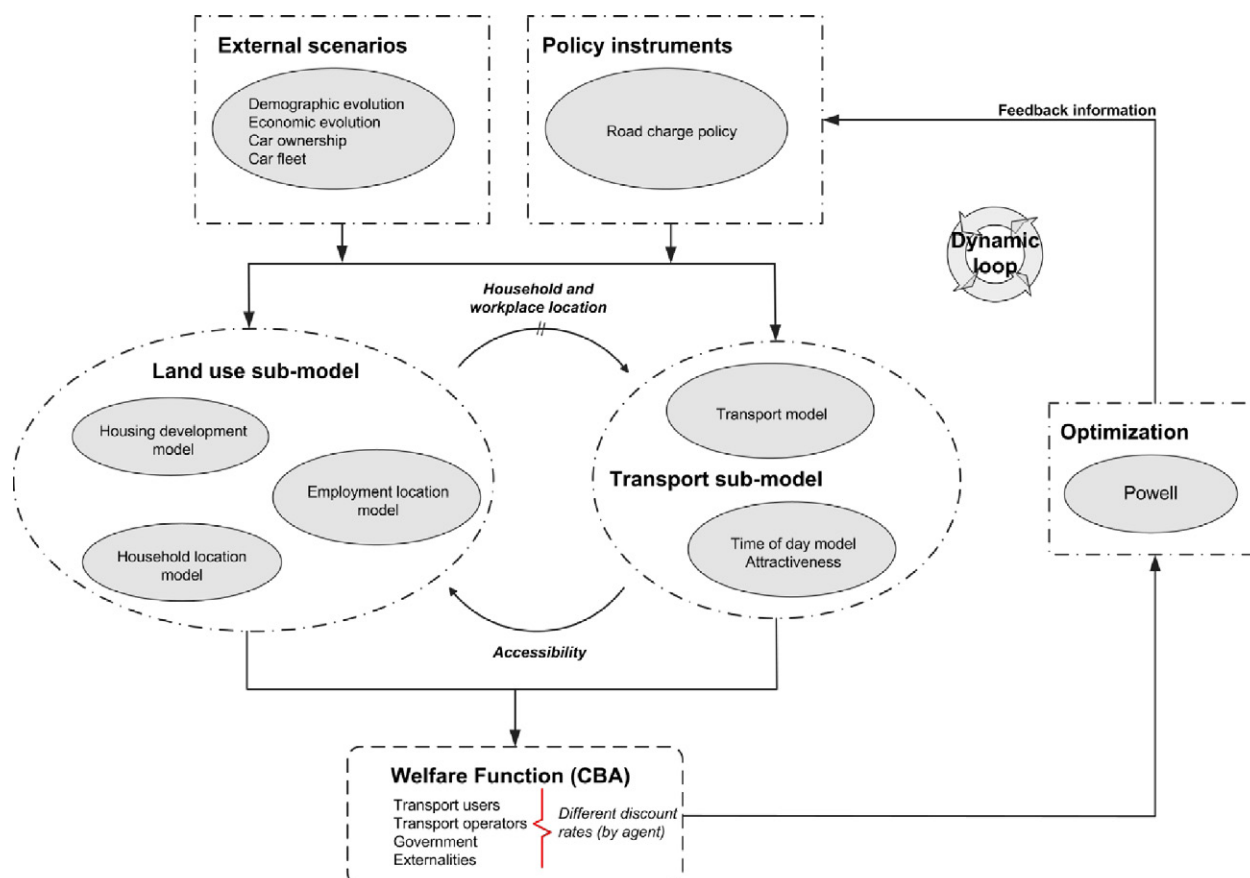
Traditionally, congestion pricing strategy welfare is assessed using a static CBA (20), (21), (22). However the analysis of the congestion pricing should take into account interaction between urban subsystems (social, environmental, land-use or activity allocations). The integrated approach of transport and land-use dynamic systems allows to estimate a social welfare function with respect to the time and space when a transport policy is implemented. The optimization of the welfare function is achieved using the NPV related to the inter-temporal preferences (i.e. discount rates) of different social agents included in the welfare function. However, the current social welfare functions used in transport policies appraisal mainly consider a unique value of discount rate. This paper looks at identifying whether the use of various discount rates following social agents' inter-temporal preferences has an effect on the definition of optimal strategy of congestion pricing implemented in a metropolitan environment.

Therefore, following the economic, transport and environmental literature about the variability of the discount rates, a new welfare function using different social rates is propounded (23). This approach intends to better reflect the real inter-temporal preferences of the single agent, their expected benefits and costs. An optimization procedure is implemented over a Land-Use and Transport Interaction model (LUTI model) in order to search for the optimal transport strategy. Three time periods (+5, +10 and +20 years) are studied to evaluate the effects of the planning process at short, medium and long terms.

This paper is organized as follows: after the introduction and related works presentation, the second section defines the methodology based on the simulation and the optimization of a congestion pricing based on a LUTI model. The optimization process of the objective function (OF) is detailed in the third section. The fourth section describes the case study of the metropolitan area of Madrid and presents the congestion pricing scenario to optimize. Section five presents an analysis of results and the comparison between the optimization process using welfare functions characterized by the same discount rate or by different discount rates related to each agent. This section includes as well a micro-territorial analysis. The last section offers conclusions about the impacts in terms of policy recommendations derived by the adoption of different welfare functions.

## GENERAL METHODOLOGY FRAMEWORK

The proposed system dynamics (SD) approach consists of linking subsystems of land-use and transport using an optimization procedure. Whereas the LUTI model estimates the mobility patterns on the scenarios conditioned by exogenous variables and policies, the optimization procedures seek the maximum welfare scenario that may be generated through the transport measures that have been optimized. Figure 1 shows the interaction between all sub-models, policy instruments, and optimization tool. The LUTI model and the optimization procedure are integrated by means of an OF, based on a dynamic CBA development. There is also a link between the optimization routine and the LUTI model through the transport policies.



**FIGURE 1. DYNAMIC LONG-TERM LOOP OF THE INTEGRATED PROCESS. BASIC STRUCTURE OF THE EVALUATION AND OPTIMIZATION MODEL.**

The core of this procedure deals with the definition of an OF which summarizes policy-makers' objectives with respect of economic efficiency, sustainability and equity and includes the utilities of all agents (users, operators, governments and society). Finally the OF is a welfare function whose optimization depends on the discount rate adopted. In general, the optimization of the welfare function considers the same discount rate for all agents included in the welfare function. This paper introduces different rates of discount, depending on the time preferences of each agent and compares the results of the optimization process using a unique discount rate or different discount rates. The optimal transport strategy is defined as the set of transport measures that maximizes the value of this function.

## The LUTI Model

A strategic, dynamic, and integrated urban land-use and transport model based on MARS (Metropolitan Activity Relocation Simulator) statements is used as the framework for policy optimization process (24). MARS-Madrid was developed since 2008 (25) and integrates elements of the land-use and the transportation systems: the basic underlying hypothesis of MARS is that settlements and activities within them are self-organizing systems. The model is based on the principles of systems dynamics (26) and synergetic (27). The development of the first MARS dates back to more than 12 years ago, and it was partially funded by the European Union research projects (OPTIMA (28), FATIMA (29) and PROSPECTS (30)). To date, MARS models have been developed for many European cities (Edinburg, Helsinki, Leeds, Madrid, Oslo, Stockholm, Bari and Vienna), some Asian cities (Chiang Mai and Ubon Ratchathani in Thailand, and Hanoi in Vietnam) and in Porto Alegre, Brazil (31). The first application of a MARS model in the United States has been recently developed for Washington DC (32).

MARS-Madrid was developed to simulate the future development of the land-use and transportation over time. The model is able to support policy evaluation and scenario testing over short, medium and long-term horizons. It uses the concepts of causal loop diagrams (CLD) from the system dynamics, which provide the basis to study the cause and effect among the variables of the transportation system and the land-use. The current version of MARS is implemented in Vensim, a System Dynamics programming environment based on the analysis of speed vs. O-D demand relationships, and includes speed-flow functions that simulate the current transport network. These functions are calibrated for Madrid Network with the VISUM® specialized transport modeling.

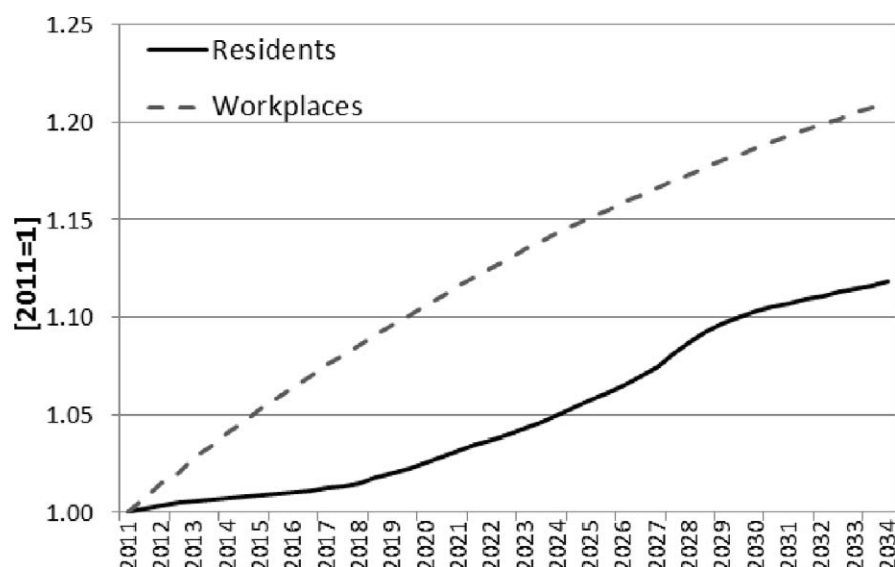
The implementation of a LUTI model for evaluating the impacts of transportation policies is a major improvement with respect to the use of traditional four-step travel demand models. MARS-Madrid includes a land-use component and explicitly simulates the interaction between the transportation system components and the relocation of residences and economic activities over time. The direct and complex relationship between transportation and the urban activity system (33) sets the basis for the instable equilibrium that exists between transportation supply and demand.

MARS-Madrid includes a transportation model, a housing development model, a household location choice model, a workplace development model, and a workplace location choice model. The transportation model simulates the travel behavior of the population that lives in each studied area, depending on the location of residences and work places. This model uses the concept of a constant travel time budget (34). The land-use model simulates the generation and allocation of new housing units and the location of workplaces for two main categories, production and services. In addition MARS-Madrid can compute energy consumption from transportation and the generation of a set of greenhouse gases (GHG) and other pollutant emissions produced by transport. Table 1 shows the main characteristics of MARS-Madrid Simulator.

**TABLE 1. MAIN FEATURES OF LUTI MODEL**

<b>Model Feature</b>	<b>MARS-Madrid Model</b>
Number of zones	90
Travel modes	Car, transport public (bus and rail), slow
Congestion effects	OD-specific speed-flow curves for trips V/C ratios)
Generalized costs	In-vehicle time, access/egress time, parking search time, waiting times, transfer times, car costs, PT fares
Journey purposes	Commute, others
Household features	Employed population, car ownership, household income
Mode and destination choice	Simultaneous choice
Demand response	Commute trips inelastic. Constant time budget
Land-use response	Yes

Pfaffenbichler, Emberger and Shepherd (35) provide additional information on the development of the first MARS model, and show how this model was calibrated and validated using data for the city of Vienna from 1981 to 2001. Guzmán describes the calibration and validation methods and data for MARS-Madrid (25). The MARS model works with a significant level of aggregation and makes long-term assessments. The model uses external forecasts for economic growth, demographic trends and car ownership obtained from the Regional Institute of Statistics of the Region of Madrid (36) and is showed in Figure 2.



**FIGURE 2. PROJECTED SOCIOECONOMIC VARIABLES [2011=1.0]**

The MARS-Madrid model has been calibrated for the regional and metropolitan area of Madrid (MARS-Madrid). Table 2 shows the modal split data that were used in the calibration of MARS-Madrid for the base year. The modal split for both commuting trips (home-work) and other trips (home-other) is calculated using the Madrid 2004 mobility survey (37). Other data inputs that were used in the project include:

- Constant travel time budget: 87 min (37).
- Average trips by worker: 2.04.
- Time value (commuting and other at prices 2004): 10.45 €/h and 5.70 €/h (38).

**TABLE 2. MODAL SPLIT CALIBRATION DATA**

Mode	Commuting trips	Other trips	Total
Slow	12.3%	24.2%	20.5%
Bus	15.7%	18.2%	17.4%
Rail	26.3%	19.3%	21.5%
Car	45.7%	38.3%	40.6%

The cost unit values for externalities (Table 3) were obtained from the European Project “Developing Harmonized European Approaches for Transport Costing and Project Assessment” (39). As shown in the above equation, the investment costs are not taken into account.

**TABLE 3. ESTIMATED EMISSIONS VALUE AND CASUALTIES AVOIDED**

Year	Avg. CO <sub>2</sub> value	Avg. NO <sub>x</sub> value	Avg. PM <sub>10</sub> value
2004-2009	22		
2010-2019	26		
2020-2029	32	5,300	2,873
2030-2039	40		
<b>Fatality</b>	<b>Severe injury</b>	<b>Slight injury</b>	
1,193,686	147,755	11,171	

Note: all costs are in prices 2004 (€)

## The Optimization Process

The optimization process enables the level of intensity of the application of certain transport policies to be defined. Optimization techniques have been an important field of research in transportation planning (40), (41), (42), (43), (44), (45), (46), (17). This paper focuses on the method developed by Powell in 1964 (47). This method is an algorithm that searches for a local minimum/maximum of OF for a set of linearly independent direction vectors without calculating the derivatives. A detailed discussion of the algorithm is given in Brent (48), and the complete algorithm is given in Press et al. (49).

The procedure of the optimization process can search through a large space of parameter values looking for optimal solutions. Firstly, it is necessary to define the OF you want to optimize. An efficient hill climbing algorithm searches through the parameter space looking for the best cumulative objective function value. Secondly, the constants of the model are chosen. Thirdly, the optimization process finds the values for those parameters that optimize the objective function (23).

This method can be applied to optimize several types of transport and land-use policies; however in this case, the optimization process to choose the best transport policy levels (i.e. toll value) is proposed with an application of two variables: a toll-pricing policy profile for passenger vehicles (initial and final toll value) in Madrid city center. The introduction of the concept of “policy profiles” allows specifying policy instrument levels and optimized them for two points over time.

We develop scenarios that simulate specific “policy profiles”: each policy can in fact be implemented with different characteristics over time: we define the main characteristics of a policy profile through  $X(t_A)$  and  $X(t_L)$  as the levels of the policy attributes respectively in the initial year  $t_A$  (the value of the policy when it is introduced) and in the short, medium and long-run (the final policy value after the intermediate adjustments). Similarly,  $t_A$  is the year in which the policy is introduced ( $t_A = 2012$  in this study) and  $t_L$  identifies the end of the evaluation period on which the policy is evaluated ( $t_L = 2017, 2022$  or  $2034$ , according the scenario). The levels of instrument in intermediate years  $X(t)$  are determined by interpolating a linear function, and the level is then assumed constant for any year after the  $t_L$  year as depicted in Figure 3.

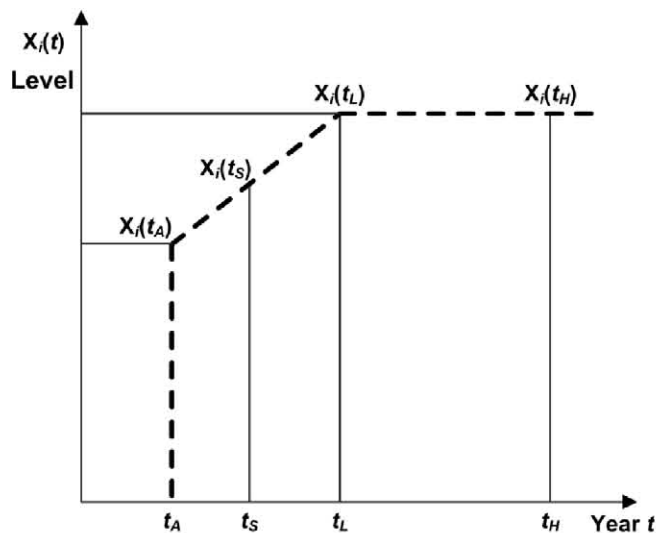


FIGURE 3. INSTRUMENT PROFILE FOR CONTINUOUS INSTRUMENTS.



## THE WELFARE OBJECTIVE FUNCTION

The OF identified with the social welfare function assembles the strategic variables that have been optimized. The objective function of the LUTI model is the welfare function (WF), including the sum of all social benefits optimized throughout the complete period of time.

Thus the WF showed in Eq. (1) measures the change in social welfare compared to the do-nothing scenario (reference scenario). This function is defined by the following elements: the change in consumer surplus ( $\Delta CS_{ijm}$ ), which includes either the monetary costs (or savings) and time savings for users, resulting through the implementation of strategy  $X$ . The variation of the operator benefits ( $\Delta O_{ijm}$ ) includes gains linked to revenues from fares and charges. The change of government benefits ( $\Delta G_{ijm}$ ) includes fuel tax revenues, and investment savings related with road costs maintenance. Finally, the variation of benefits for the society related with the external costs ( $\Delta E_{ijm}$ ) includes reduction of accidents, greenhouse gas emissions and pollution costs.

$$WF = \sum_{t=0}^n \sum_{ijm} \left[ (1/(1+r_u)^t) \cdot \Delta CS_{ijm}(t) + (1/(1+r_o)^t) \cdot \Delta O_{ijm}(t) + (1/(1+r_g)^t) \cdot \Delta G_{ijm}(t) + (1/(1+r_e)^t) \cdot \Delta E_{ijm}(t) \right] \quad (1)$$

The final evaluation is expressed by net present value (NPV) over the different scenarios, and using different discount rates ( $r_u, r_o, r_g, r_e$ ) according with the considered social agents (users, operators, government, society). The government and the society social discount rate in this paper will be the same. The variable  $t$  represent the period of time. The variable  $m$  is the transport mode. The  $i$  and  $j$  subscripts refer to origin and destination zones, respectively.

It is well known that the consumer surplus from a change in travel times and/or travel costs should in general be calculated at the level of origin-destination pairs.

$$\begin{aligned} \Delta CS_{ijm}(t) &\approx \frac{1}{2} \sum_t \sum_{ijm} [T_{ijm}^0(t) + T_{ijm}^1(t)] \cdot [G_{ijm}^0(t) - G_{ijm}^1(t)] \\ &\approx \frac{1}{2} \sum_t \sum_{ijm} [T_{ijm}^0(t) + T_{ijm}^1(t)] \cdot (C_{ijm}^1(t) + t_{ijm}^1(t) \cdot VOT_i - C_{ijm}^0(t) - t_{ijm}^0(t) \cdot VOT_i) \end{aligned} \quad (2)$$

Where  $T_{ijm}^k$  is the demand for trips between  $i$  and  $j$  by mode  $m$ , in the  $k$  scenario;  $G_{ijm}^k$  is travel generalized cost;  $C_{ijm}^k$  is total travel cost including charging and operation cost;  $t_{ijm}^k$  is the travel time; and  $VOT_i$  is the value of time. The superscript  $k$  is used to denote either the do-nothing scenario ( $k=0$ ) or the scenario that is tested ( $k=1$ ).

Consumer surplus (i.e., the difference between user utility and its cost) implied a higher consideration for the high income users because it increases with the income of users. In other words, the consumer surplus of high income people has a higher weight with respect of the low income people. In this work, the income of people is included in the user utility, to partially correct this possible distortion. Travel cost  $C_{ijm}^k$  includes the cost of charging (like a congestion toll or parking charging) and operation costs, as shown in Eq. (3).

$$C_{ijm}^k(t) = F_{ijm}^k(t) + \tau_{ijm}^k(t) \quad (3)$$

Where  $F_{ijm}^k$  is the operation costs (including fuel) between  $i$  and  $j$  by mode  $m$ , in the  $k$  scenario; and  $\tau_{ijm}^k$  is the cost of road charging. The operators' cost is calculated by Eq. (4) and shows the value of net benefits to operators, including public transportation (PT) fares and toll and parking revenues (17).

$$\Delta O_{ijm}(t) = \sum_t \sum_{ijm} T_{ijm}^1(t) \cdot [\sigma_{ijm}^1(t) + c_{ijm}^1(t)] - T_{ijm}^0(t) \cdot [\beta_{ijm}^0(t) + c_{ijm}^0(t)] \quad (4)$$

$\beta_{ijm}$  consists in two parts, one is revenue from private vehicles in the case of an urban toll or parking charge fee; another part is constituted by the revenue collected from public transport services, e.g. trip tickets, while  $c_{ij}$  represents the cost of administration, operation and maintenances costs.

Equation (5) represents the government's benefits or losses resulting from changes of fuel tax revenue ( $\Delta F_{ij}$ ) and the variation of the cost of road maintenance ( $\Delta M_{ij}$ ). Finally, equation (6) represents the value of external costs, associated with green-house gas emissions ( $\Delta GHE_{ij}$ ), air pollution ( $\Delta P_{ij}$ ) and road safety ( $\Delta S_{ij}$ ).

$$\Delta G_{ijm}(t) = \sum_t \sum_{ijm} [T_{ijm}^1(t) - T_{ijm}^0(t)] \cdot [F_{ijm} + M_{ijm}] \quad (5)$$

$$\Delta E_{ijm}(t) = \sum_t \sum_{ijm} [T_{ijm}^1(t) - T_{ijm}^0(t)] \cdot [GHE_{ijm}(t) + P_{ijm}(t) + S_{ijm}(t)] \quad (6)$$

Equations (2), (4), (5) and (6), represents each agent and their costs and benefits and discount rates, are included in the equation (1). The NPV is calculated according to the discount rate for each agent.

The different discount rates for each kind of social agents are defined following the micro-economic and CBA literature (50). In general the users prefer to consume today than tomorrow (10). Hence, the social time preferences estimated for users is between 0.5 and 1% higher than the government discount rate (51). Some studies in Spain recommend a discount rate of 4.8% (51). Another studies that present methodologies for the design of optimal transport strategies using LUTI models in UK, use a discount rate of 3.5% to reflect UK practice (46) (44). Actually, the society is the social agent having the higher preference for the future generation, having a discount rate lower than the current users. Hence the considered discount rate for users is 5.5%, while for government is 4.5% (52). Finally, the operators' discount rate is related with the expected investment value, i.e. between 7% and 10% (53).

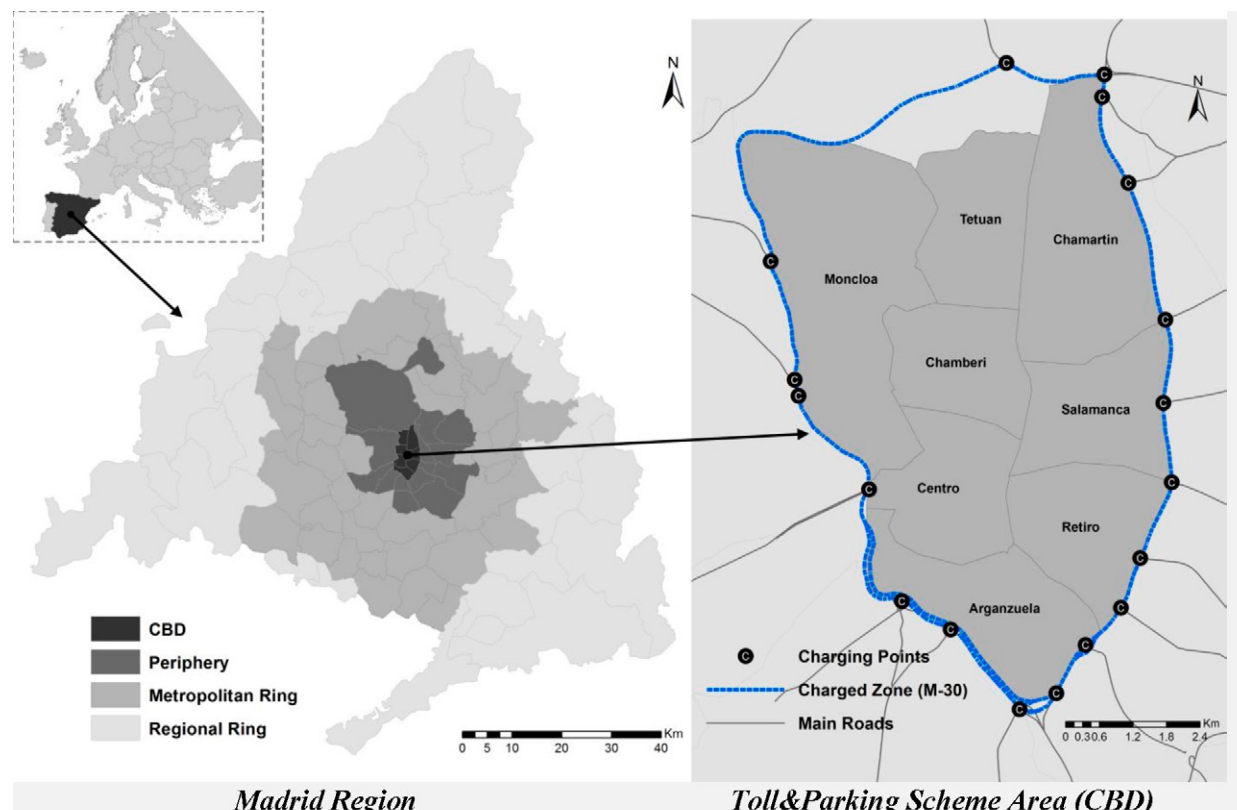
## MADRID CASE DESCRIPTION

The Madrid city center area is about 54.8 km<sup>2</sup>. In 2004, around 250,000 of the inhabitants of this area travel by car to their workplaces outside the cordon. Additionally, almost 260,000 people live outside the cordon and have their workplaces inside, and commute by car from outside to inside of the cordon area (54). Figure 4 shows the basic geographical information used in the model.

The MARS- Madrid model includes 90 zones covering the whole region, 61 of which correspond to urban and metropolitan areas. The cordon area defines a zone of the city in which access is restricted to private vehicles, in order to reduce pollutant emissions in the center of Madrid. For this case the zone selected as a trial was the area inside the ring road known as the M-30 (Figure 4). The area of study has a high provision of public transportation, both in terms of coverage and service. In the forecast scenarios, projections were made for economic and population growth based on data from the Institute of Statistics in Madrid (36).

It is presumed that tolls are automatically charged to drivers as they pass –without stopping– through several toll barriers located as shown in Figure 4. The transportation cost of each pair  $ij$  of the network is considered as a vector having two components: the monetary cost and the monetary value of time, which measure the subjectively-perceived expense of a journey using generalized costs weighted by exponential functions of the user's perception. It is also assumed that the toll-road user will pay the same

toll regardless of the car type or the resident zone in which he lives (except for CBD residents). In the do-nothing scenario there is no toll to pay for travel to the city center.



<i>Madrid Region</i>		<i>Toll&amp;Parking Scheme Area (CBD)</i>			
	<b>Tolled Zone</b>	<b>Rest of Modeled Area</b>			<b>Modeled Area</b>
	<i>CBD</i>	<i>Periphery</i>	<i>Metropolitan Ring</i>	<i>Regional Ring</i>	<i>Total</i>
Population	1.013.364	2.256.497	2.722.751	501.891	6.494.503
Workplaces	449.370	1.000.630	531.395	92.561	2.073.956
Area (km <sup>2</sup> )	41,18	565,20	2.272,60	5.151,70	8.031
Modal Split (PC/PT) [%]	43/57	42/58	68/32	89/11	52/48
Car/1,000 inhabitants	438,18	388,68	521,39	816,81	511,96

**FIGURE 4. MODELED AREA AND CITY CENTER AREA – MADRID.**

## SCENARIOS DEFINITION

In order to explore the optimal toll scheme values under different discount rates and time horizons, an integrated framework was proposed seeking the maximum social welfare. These dimensions were compared with business-as-usual alternatives (labeled the do-nothing scenario), where no policy measures were assumed. This scenario includes only infrastructures built in 2012 and does not consider any intervention during evaluation periods. Under a do-nothing scenario, the social welfare variation is assumed to be zero. Do-nothing scenario is needed to quantify the impact of transportation policies. The optimum toll value obtained in alternative scenario behind the condition of the maximization of the NPV of the WF proposed will measure the social welfare compared to the reference scenario.

By combining discount rates and time periods, the scenario framework is defined. Hence, six groups of scenarios were identified (the first three for the same rates for all social agents, and 4, 5 and 6 for different discount rates for each agent) for metropolitan area of Madrid:

**TABLE 4. OPTIMIZED SCENARIOS**

Scenario	Code	Initial year	Final year	Discount rates ( $r_a$ )			
		$t_A$	$t_L$	<i>Users</i>	<i>Operators</i>	<i>Government</i>	<i>Externalities</i>
Same rates and short term	[SR-ST]	2012	2017	4.8%	4.8%	4.8%	4.8%
Same rates and medium term	[SR-MT]	2012	2022	4.8%	4.8%	4.8%	4.8%
Same rates and long term	[SR-LT]	2012	2034	4.8%	4.8%	4.8%	4.8%
Different rates and short term	[DR-ST]	2012	2017	5.5%	7.0%	4.5%	4.5%
Different rates and medium term	[DR-MT]	2012	2022	5.5%	7.0%	4.5%	4.5%
Different rates and long term	[DR-LT]	2012	2034	5.5%	7.0%	4.5%	4.5%

## ANALYSIS OF RESULTS

As expected, car traffic entering the cordon zone is reduced at the end of the time period (2017, 2022 and 2034). There is a modal shift from car to PT in radial trips (periphery to center). This modal shift results in a PT fare revenue surplus. In addition, the capacity surplus produces a scenario with lower congestion in radial corridors (Figure 4). The increasing speed improves the trip time for car users, as well as for road-shared PT services. A general time savings for private and PT users is generated. However, a percentage of radial car trips (between 3 and 5%, according to the scenario) have changed their destination pattern, intensifying the loss of attractiveness of the tolled city center compared to the rest of the region. In the case of internal city center mobility, the current scenario produces a reduction of the use of roads in the city center that decreases the delays. The main consequence is an increasing of car use by the city center residents excluded from paying a toll. These dynamics may require an adaptation of the tolling scheme or it may need to be complemented with other transport policies, e.g., a new parking scheme (55). Table 5 summarizes the optimal strategies for the welfare function maximization.

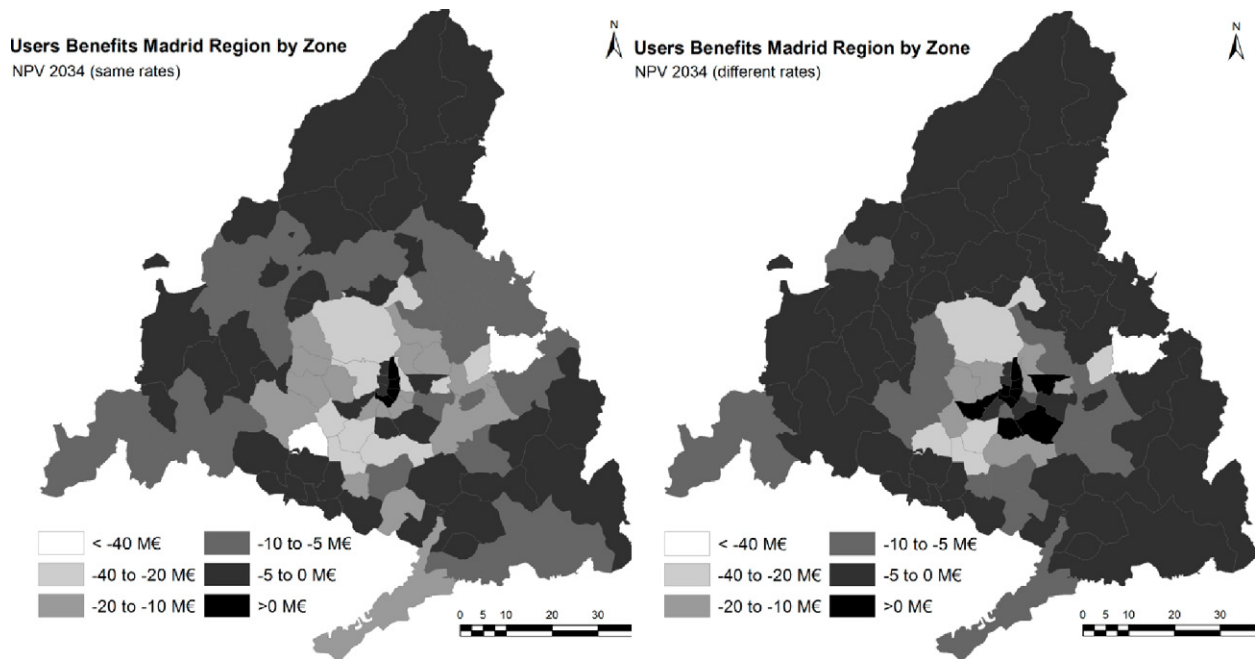
The WF optimal strategy shows a general positive social welfare enough to cover the generated costs. Even if the general losing agent is the car user for whom the increased saving time is not enough to cover the monetary costs. This effect is more visible if we analyse the situation at local scale, comparing users characterized by different income and spatial localization. The people from the low income district of Madrid City (Usera district with 1,200€ for household per month) lose more benefits, around 65-75% with respect to richest zones, while the users with the higher income (3,500€ for household per month) didn't change their pattern's schemes and their costs increase less compared to the time saving they realize. A municipality quite far from the city center of Madrid and from the tolled area, characterized by a quite high income (3,000 € for household per month, like Pinto, see Figure 5), is less affected by the congestion charge because of the lower use of the tolled area and a quite high income. This first funding seems to say that the congestion pricing is a regressive policy measure.

**TABLE 5. SURPLUS ALTERNATIVE SCENARIO/REFERENCE SCENARIO OF THE MADRID ROAD CHARGE SCHEME FOR THE OPTIMAL TOLL VALUE [NPV M€]**

Scenario		[SR-ST]		[SR-MT]		[SR-LT]		[DR-ST]		[DR-MT]		[DR-LT]	
Welfare (M€)		93.57		169.18		309.11		74.85		119.08		167.58	
Toll value optimum	Year	$t_A$	$t_L$	$t_A$	$t_L$	$t_A$	$t_L$	$t_A$	$t_L$	$t_A$	$t_L$	$t_A$	$t_L$
		2012	2017	2012	2022	2012	2034	2012	2017	2012	2022	2012	2034
	Value (€)	$X(t_A)$	$X(t_L)$	$X(t_A)$	$X(t_L)$	$X(t_A)$	$X(t_L)$	$X(t_A)$	$X(t_L)$	$X(t_A)$	$X(t_L)$	$X(t_A)$	$X(t_L)$
		1.6	2.3	1.8	2.5	2.3	2.1	1.5	2.5	1.7	2.2	2.3	0.2
Users (M€)													
Time savings													
Car users		126.10		232.73		418.64		124.43		211.07		285.64	
PT users		93.67		169.79		290.40		92.60		153.72		201.59	
Money savings													
Car users		-483.91		-891.37		-1,556.11		-484.36		-788.94		-995.88	
PT users		0.00		0.00		0.00		0.00		0.00		0.00	
Total benefit users		-264.14		-488.85		-847.07		-267.33		-424.15		-508.66	
Operators (M€)													
PT fares revenue		18.32		33.26		56.32		17.49		27.84		34.58	
Parking charges revenues		-97.98		-176.56		-298.92		-94.17		-147.32		-180.94	
Congestion pricing revenues		453.22		830.39		1,451.61		434.96		690.08		859.41	
Total benefit operators		373.56		687.09		1,209.32		358.28		570.59		713.04	
Government (M€)													
Fuel tax revenues		-18.35		-34.10		-63.65		-18.76		-32.10		-43.80	
Road maintenance costs		1.90		3.53		6.38		1.95		3.27		4.24	
Total benefits government		-16.45		-30.57		-57.28		-16.81		-28.82		-39.53	
Externalities (M€)													
Environmental benefits		3.53		6.80		13.41		3.62		6.38		8.91	
Accidents costs		-2.93		-5.29		-9.27		-2.91		-4.93		-6.15	
Total benefit externalities		0.60		1.51		4.14		0.71		1.46		2.76	







**FIGURE 5. USERS BENEFITS BY ZONE AND SCENARIO**

The time saving, is significant after the cordon toll implementation. The increased accident rate caused by a higher speed in the charging area leads to higher accident costs. Anyway travelers pay a higher price (time and costs including the pricing policy) than the time costs they save with the congestion pricing. Total social welfare is positive because the operators' revenue collection dominates travelers' surplus reduction. These results highlight that this policy may have a strong social opposition as user surplus is negative. Nevertheless, the real case of congestion pricing shows an increasing acceptability of an urban congestion toll (56). The main reason is the jointly implementation of a public transportation policy that increase PT services and pay a major attention to the more losing zones. Congestion pricing schemes generate significant positive present value of revenue which may lead to promote complementary public transport measures compensating the increasing generalized costs for users.

Comparing the results between the optimization process using same rate or different rates among social agents, we observe that in general the use of discount rates following the suitable social time preferences for each kind of actors decreases the social welfare in the medium and long terms. The short term, seems to be the same. The use of different discount rates for agents shows that the optimal value for toll is strongly decreasing with respect to the use of the same discount rate. As above said a positive social welfare is generated because toll charges revenues dominates the travelers' surplus reduction. But, as the value of potential future revenues for operators decreases in time faster than the disutility to users because of the differences on time preferences (translated into different discount rates), the tolling scheme undergoes a relevant change through de different DR-n scenarios. Values for  $X(t_A)$  and  $X(t_L)$  vary from 1.5-2.5 € at the DR-ST scenario to 2.3-0.2 € for the DR-LT scenario. Individual user interests gain weight on the welfare function as operator interests for future decline. The expected revenues decline over time so optimal toll value will trend to reduce negative effects on user surplus rather to improve the capability to generate new incomes. This drives to the pronounced change over time in the tolling scheme. Consequently, the loss in terms of NPV for users and government is decreasing, and there is a gain for the operators. Although benefits and costs (B/C) ratios obtained in all optimal scenarios are nearly constant.

This is a very important advance in the literature of the CBA analysis implemented to appraise transport policies: the use of the real social inter-temporal preference rate for each actor represents at more realistic utility of each social actor. A future development could be the introduction of different discount rates with respect of the different groups of users, or government or operators.

From a time perspective of marginal changes of social welfare, it declines overtime for all scenarios (Figure 6). This trend is more pronounced when we apply different discount rates (DR scenarios). Individual user interests prevail over the rest of agents, especially over the interest of operators in creating new revenues due to his higher discount rate that undervalue future gains. This causes an inconsistency of the policy between operators and the rest of social agents.

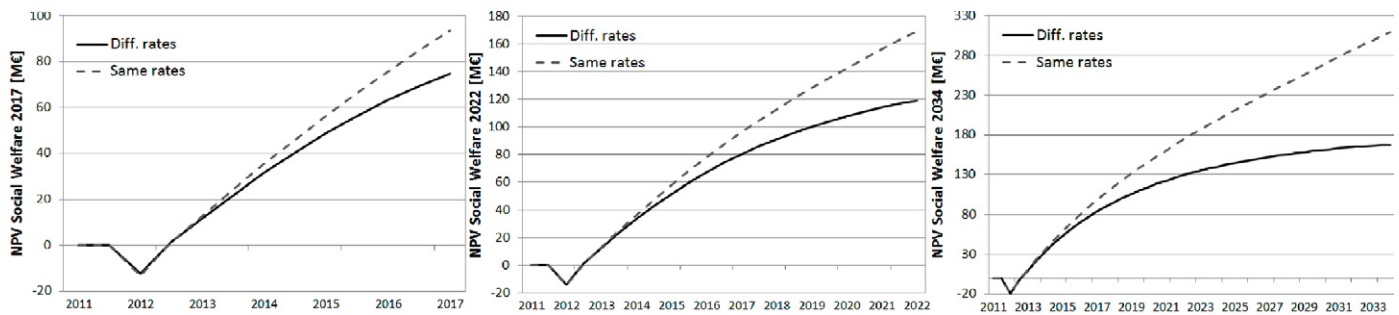


FIGURE 6. WELFARE OBJECTIVE FUNCTION

## CONCLUSIONS

Discounting future benefits and costs is almost universal in CBA approach. In general, future benefits and costs receive smaller weight than the imminent ones. The chosen discount rates determine the magnitude of the difference between current and future costs/benefits. Different agents with different time preferences, risk, and opportunity may be affected by transportation projects. Therefore using a unique discount rate to homogenize time dependent costs and benefits in a social welfare may be inaccurate. This research looks to identify whether the use of more suitable discount rates for each social actors had an effect on the selection and definition of optimal strategy of congestion pricing. At the same time, different conclusions regarding impacts of the policy are also revealed.

The following four conclusions could be addressed:

1. Optimal congestion pricing increases the costs of passenger vehicle use and therefore reduces the traffic volume, especially for periphery-CBD trips. This in turn increases demand for PT as well as reduces travel time for all traffic flows. Hence, congestion pricing leads to an improvement in environmental conditions as it reduces passenger private vehicle traffic. In general, the total social benefit for cordon toll scheme is positive in all scenarios. Even though in all cases, optimal congestion pricing scheme produce a decreasing consumer surplus, especially for lower income people.
2. When different discount rates are applied, shortsightedness by operators with its higher discount rate appears inconsistent with community expectations with a lower discount rate. If no other measure is deployed in order to recycle operator surplus obtained into users, the usefulness of the measure of congestion toll declines over time. This leads to an optimal tolling scheme in the scenario DR-LT where the toll decreases nearly to zero in the long term as individual preferences gains over potential expected revenues of operators.



3. If the revenue from a congestion toll is not returned to users, the social welfare declines. In particular, when all road users suffer identically from a delay and the toll revenue is not recycled in favor of the users, the toll just reduces users' welfare and this may lead, not only to a social unacceptable measure but to an ineffective measure from a social welfare point of view. However, congestion pricing have an important role for city planners. Other transport measures, improving PT measures for example, may have a positive user surplus at the expenses of generating negative financial impacts on operators which may lead to increase subsidies to PT. Revenues from congestion pricing may be recycled to cover these subsidies required making both measures complementary. Instruments may mutually reinforce as the effectiveness, acceptability and economic support are improved. The acceptability problem of the congestion charge is overcome and mitigated. Added to this, congestion pricing instrument may finance complementary instruments and, thus, subsidization is less necessary if congestion pricing are in place. This highlights the need for planners in the packaging of different policy instruments to form an overall strategy. Moreover, if complementary measures were optimized jointly, an optimal level for recycling revenues from congestion pricing would be achieved.

4. A social welfare analysis from a geographical point of view illustrates that aggregate social welfare as a sum of surpluses ignores equity issues, which may be socially unacceptable because tolls penalize some people for the benefit of others. The analysis showed that the charge discourages car trips of lower income travelers more than the trips of higher incomes people. Toll revenues can be used to compensate those who might otherwise "lose" as a result of congestion pricing. Without recycling of the toll revenues, the congestion toll is definitely a regressive measure. Recycling revenues is thus a way of redistribution of wealth.

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